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Reducing Secondary Insults in Traumatic Brain Injury



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1.0 SUMMARY

This was an observational study that continuously monitored intracranial pressure (ICP) of traumatic brain injury (TBI) patients during in-theater aeromedical transport of Air Force Critical Care Air Transport Team casualties during flights from Bagram to Landstuhl Regional Medical Center and from Landstuhl to the U.S., as well as in-hospital transport from the intensive care unit to computed tomography scan. There were complete data on 11 patients in the aeromedical portion of the study and 7 patients in the in-hospital portion. Data analysis showed that in both the in-theater and in-hospital portions of the study, some patients experienced many instances of ICP >20 mmHg while others experienced none. All but one patient in each group experienced an ICP fluctuation of $\pm 50\%$ of baseline ICP. Overall, in-hospital transport and movement to and from the computed tomography table produced larger ICP increases than during aeromedical transport. It is unclear if there was a mortality effect of the ICP variations due to the observational nature of the study. A larger study including the in-flight and post-flight medical records would be needed to determine the overall effect of transport.

2.0 INTRODUCTION

This study was composed of two parts: (1) Effects of Transport on Outcomes in Traumatic Brain Injury (TBI) and (2) Effects of Aeromedical Transport on TBI. The aims of the study were to evaluate the effects of patient movement and transport on intracranial pressure (ICP) during aeromedical transport of Critical Care Air Transport Team (CCATT) patients and during transports to computed tomography (CT) scan in a civilian trauma medical center.

3.0 BACKGROUND

3.1 Effects of Transport on Outcomes in TBI

Traumatic brain injury claims the lives of more than 56,000 persons in the United States each year, results in hospitalization for another 373,000 persons, and leaves 99,000 persons permanently disabled [1]. The total cost for treatment and rehabilitation of patients with brain injuries is estimated at \$48.3 billion annually, and this figure does not include the cost to society of lost years of productivity [2]. Although prevention should be the first priority in addressing the epidemic of TBI, previous studies suggest that secondary insults such as hypoxia and hypotension may worsen a brain injury once it has occurred [3-13]. Recent recognition that secondary brain insults are primary determinants of outcome for severely brain-injured patients has heightened emphasis on preventing these secondary insults. However, the data in most previous studies on this topic are either registry based or retrospective or include only secondary insults that occur in the intensive care unit (ICU) setting. Most prior investigations have provided limited information on secondary insults occurring during transport. We hypothesize that secondary brain insults may occur frequently during in-hospital and en route care transport in patients with brain injury. We additionally hypothesize that automated data collection devices utilized during transport could more reliably document the frequency of these events and help us understand the causes. Understanding the causes will allow us to design processes to prevent these untoward events.

3.2 Effects of Aeromedical Transport on TBI

The increasing prevalence of TBI is a recognized phenomenon in the current theaters of Operations Iraqi Freedom and Enduring Freedom. This is a reflection of the increasing exposure of combatants to improvised explosive devices and other explosive ordnances. The resultant injury patterns take the form of either blunt force trauma or direct penetrating intracranial injuries. These injuries result in cellular trauma and resultant edema of central nervous system tissue within the closed confines of the cranial vault. The ability to establish and maintain an appropriate assessment of the intracranial pressure of a TBI patient is fundamental of care for these injured soldiers. The tactical and austere setting of combat medicine makes the precise measurement and monitoring of ICP an even more daunting task.

Our group has recently demonstrated the capability to continuously monitor ICP during evacuation for TBI patients transported by CCATT teams from Balad Air Base to Landstuhl Regional Medical Center. In this preliminary feasibility study, our group demonstrated that the equipment set produced a valid data stream that provided ICP, mean arterial pressure (MAP), and motion data (three-axis accelerometer) every 5 seconds over the 10-hour duration of transport from Iraq to Germany (Johannigman J. Personal data collection; 2003).

The ability to accurately and continuously monitor ICP offers distinct advantages for the military and is well aligned with the current military research initiatives investigating TBI. The first advantage of continuous monitoring is that it allows the clinician to target therapeutic interventions (osmotic agents, elevation, and craniectomy) in a timely fashion, in a setting where every moment counts. Early situational awareness of elevated intracranial pressure may allow for earlier corrective actions that mitigate the severity of secondary injury to the already compromised brain.

The second potential advantage of this protocol is that continuous monitoring provides an opportunity to establish algorithms of care that utilize ICP and cerebral perfusion pressure (CPP) as endpoints of therapy. If it is possible to demonstrate that ICP may be accurately tracked in a continuous fashion, then it is possible to consider the development of autonomous controller systems that augment the practitioner by constantly monitoring and optimizing the CPP. These systems would be invaluable in the austere and far-forward setting where clinician situational awareness is constantly challenged by tactics and environment. The potential of utilizing these endpoints (ICP monitoring and avoidance of secondary injury) during the evacuation process offers a dramatic potential opportunity for elevating the intensity of monitoring and therapy during en route care of the patient with traumatic brain injury.

Presently, the options for neurologic monitoring available to CCATTs for aeromedical transportation do not permit dynamic assessment of ICP during critical aspects of the flight (i.e., takeoff and landing). In best-case scenarios, ICP is manually recorded at intervals by medical personnel and CCATT members. Knowledge regarding changes in ICP during the evacuation process may serve as the basis for future development of more effective en route care equipment, improve the training of aeromedical evacuation providers, and improve overall patient safety in both the military and civilian setting. The ability to longitudinally monitor ICP data throughout a CCATT mission will provide awareness of potentially significant events that occur during ground transportation, tactical takeoff and landing, and care at altitude. This “first-of-its-kind” study will provide groundbreaking visibility regarding the scope of ICP issues in the combat casualty with TBI and propose potential medical solutions.

4.0 METHODS AND PROCEDURES

4.1 Effects of Transport on Outcomes in TBI

All patients in the surgical and neurosurgical ICU diagnosed with a traumatic brain injury requiring a diagnostic procedure were eligible for the study. The study was observational in nature. Prior to the diagnostic procedure, patients were placed on two additional pieces of monitoring equipment. The first was connected to the physiologic transducers already used for monitoring arterial blood pressure and intracranial pressure. The signals from these transducers were split. One output was connected to the standard of care monitors used by the ICU nurses for monitoring patients during diagnostic procedures. The second output was connected to a data recorder that recorded measurements of blood pressure and ICP to a hard drive every second. These data were written to a .csv file to allow for later analysis. If the patient did not have an ICP monitor that could be connected to the data recorder, only blood pressure was recorded. Only patients who had consented to participate in the study were connected to the additional monitoring devices that were used in the study.

Figure 1 shows the data recorder. It operates from four AA batteries. The device weighs less than 1 pound and can be carried in the palm of your hand. For purposes of the study, the device was mounted to the patient's bed or transport stretcher.

All patients were unable to sign consent secondary to their injuries and were considered vulnerable. Consent was obtained from next of kin or legally authorized representative. The inclusion/exclusion criteria are described below.

Inclusion criteria

- Presence of TBI
- Requires mechanical ventilation
- Presence of an indwelling arterial catheter for monitoring blood pressure
- Age > 18 years

Exclusion criteria

- Age < 18 years
- Diagnosis of brain death
- Non-English speaking persons
- Prisoners
- Mentally ill persons



Figure 1. Data Recorder

4.2 Effects of Aeromedical Transport on TBI

The study was observational in nature. Institutional Review Board approval was obtained from Wright-Patterson Air Force Base. This was a prospective study of data already being collected as a routine part of care. This study allowed collection of data for review. Monitoring began when the patient was prepared for transport and included movement on the ambulance bus and in the aircraft. The monitoring system consisted of a small electronic data logging device, which was connected in parallel with the current ICP monitoring device. As dictated by the electronic design of the data logger, all data points were routinely recorded to the data logger

every 5 seconds. The system recorded pressures (e.g., ICP and MAP) and did not collect any personal health information. The data had no identifiers linked to the patient. At the conclusion of the CCATT mission, the accumulated data fields stored in the data logger were downloaded to a conventional storage device (thumb drive, PC card) for subsequent analysis. Data analysis was conducted on the data streams saved to external software programs. The study duration was 6-10 hours for each patient.

Files were saved to the hard drive of a password-protected computer and reviewed retrospectively. Data analysis included identification of the number of events with ICP > 20 mmHg and the duration of these events. We evaluated changes in ICP with times for takeoff and landing for the specific aircraft used on that day for transport. The accelerometer included in the device allowed us to determine takeoff and landing. The effects of takeoff and landing were distinguished by aligning data from the data logger accelerometer against the simultaneous data streams of ICP, MAP, and CPP. In addition, the CCATT members were asked to note takeoff time, altitude upon reaching cruising altitude, and any significant changes in altitude and time of descent. There were no interventions and as such no changes in patient risks. We monitored individual files to verify quality of the data. The planned data collection qualified as less than minimal risk. All patient care and equipment were the standard of care. Data collected continuously to the data logger were not visible to the caregivers. ICP was monitored and displayed on the Propaq physiologic monitor. ICP was recorded manually by nursing personnel. Recording of ICP by the caregivers is a standard of care.

4.3 Selection of Subjects

A convenience sample of patients requiring ICP monitoring and transport from Craig Joint Theater Hospital, Bagram Air Field, Afghanistan, to Landstuhl Regional Medical Center, Germany, were studied. This study used active duty, activated Reservists, and National Guard/Air National Guard warfighters and U.S. civilians and contractors as subjects. Patients sustaining traumatic brain injury and subsequently requiring intracranial pressure monitoring were evaluated in this observational study.

Subject Inclusion: Subjects included in this study were U.S. military personnel, Department of Defense personnel, or civilian contractors eligible for evacuation by the U.S. Air Force aeromedical evacuation system. Subjects had sustained a traumatic brain injury and had both an external ventricular drainage device and an existing arterial pressure monitor placed for standard care.

Subject Exclusion: Subjects meeting any of the following criteria were excluded from participation in the study:

- Subjects with TBI without an external ventricular drainage device
- Subjects without an existing arterial pressure monitor
- Detainees or enemies of peace

5.0 RESULTS

For both the in-theater and in-hospital portions of the study, continuous ICP measurements were recorded and then downloaded and analyzed. The length of the recordings was much longer for the in-theater portion, ranging from 467-2273 minutes versus 11-43 minutes for the in-hospital portion, making for large differences in the amount of data and incidences of ICP variability. The parameters analyzed were instances of ICP > 20 mmHg and instances of variation of ICP \pm 50% of the baseline ICP and the duration of each instance. Table 1 shows the number of instances of ICP > 20 mmHg in the in-theater portion (range 0-238) and duration of instances (range 0-11 seconds). Table 2 shows the number of instances of ICP \pm 50% of the baseline ICP in the in-theater portion (range 0-921 seconds) and duration of instances (range 0-9054 seconds). Table 3 shows the number of instances of ICP > 20 mmHg in the in-hospital portion (range 0-11 seconds) and duration of instances (range 0-479 seconds). Table 4 shows the number of instances of ICP \pm 50% in the in-hospital portion (range 0-8 seconds) and duration of instances (range 0-1547 seconds). All four tables also include the total, median, and interquartile ranges (IQRs) of the duration.

Table 1. In-Theater ICP > 20 mmHg

| Observation No. | Instances | Total Duration (s) | Median (IQR) (s) | Range (s) |
|-----------------|-----------|--------------------|------------------|-----------|
| 1 | 39 | 1,151 | 23 (16-34) | 11-95 |
| 2 | 0 | 0 | 0 | 0 |
| 3 | 10 | 302 | 13 (12-19) | 11-165 |
| 4 | 238 | 9,445 | 19 (13-15) | 11-1160 |
| 5 | 3 | 41 | 14 (12-15) | 12-15 |
| 6 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 0 | 0 |
| 8 | 12 | 647 | 17 (13-34) | 12-298 |
| 9 | 17 | 23,514 | 1588 (457-2042) | 30-3281 |
| 10 | 0 | 0 | 0 | 0 |
| 11 | 0 | 0 | 0 | 0 |

Table 2. In-Theater ICP \pm 50% of Baseline

| Observation No. | Instances | Total Duration (s) | Median (IQR) (s) | Range (s) |
|-----------------|-----------|--------------------|------------------|-----------|
| 1 | 10 | 197 | 18 (16-19) | 13-37 |
| 2 | 27 | 16,585 | 48 (31-153) | 13-9054 |
| 3 | 35 | 914 | 20 (14-30) | 11-146 |
| 4 | 155 | 4,226 | 18 (13-30) | 11-569 |
| 5 | 921 | 61,183 | 23 (17-38) | 11-4144 |
| 6 | 36 | 1,127 | 24 (15-37) | 11-146 |
| 7 | 19 | 4,028 | 35 (17-337) | 13-1192 |
| 8 | 10 | 1,161 | 49 (16-126) | 13-558 |
| 9 | 27 | 17,208 | 160 (29-805) | 12-2801 |
| 10 | 6 | 1,128 | 98 (25-282) | 18-608 |
| 11 | 0 | 0 | 0 | 0 |

Table 3. In-Hospital ICP > 20 mmHg

| Observation No. | Instances | Total Duration (s) | Median (IQR) (s) | Range (s) |
|-----------------|-----------|--------------------|------------------|-----------|
| 1 | 0 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 |
| 3 | 4 | 611 | 123 (32-274) | 22-344 |
| 4 | 0 | 0 | 0 | 0 |
| 5 | 11 | 960 | 35 (15-48) | 13-479 |
| 6 | 0 | 0 | 0 | 0 |
| 7 | 8 | 358 | 29 (17-54) | 14-146 |

Table 4. In-Hospital ICP \pm 50% of Baseline

| Observation No. | Instances | Total Duration (s) | Median (IQR) (s) | Range (s) |
|-----------------|-----------|--------------------|------------------|-----------|
| 1 | 3 | 93 | 32 (18-43) | 18-43 |
| 2 | 0 | 0 | 0 | 0 |
| 3 | 4 | 541 | 121 (27-271) | 14-340 |
| 4 | 4 | 534 | 97 (32-235) | 18-322 |
| 5 | 7 | 749 | 103 (16-203) | 15-263 |
| 6 | 5 | 1738 | 52 (47-69) | 23-1547 |
| 7 | 8 | 591 | 29 (22-72) | 14-332 |

6.0 DISCUSSION

Although only a small number of patients had complete data to analyze, the data show that patient movement in both the aeromedical and hospital environments can cause large fluctuations in ICP values and possible untoward effects on patients' conditions. During hospital transport, although the duration is much shorter than aeromedical transport, there can be wide variations in ICP due to movement of the patient through hallways, on and off elevators, and on and off the CT table (Figures 2-4). Agitation and the requirement for additional sedation often were necessary to alleviate or prevent the effects of this movement and the adverse effects on ICP.

During aeromedical transport, fluctuations in ICP appeared to be less extreme, probably due to use of higher sedation doses and the hemicraniectomy that most casualties received prior to being transported, although the length of transport produced more incidences of ICP derangement. Takeoff and landing are arguably the points in the transport that would affect ICP to the greatest degree. Takeoff produces the greatest physiologic pressure changes in the body (blood pressure, ICP, CPP, etc.). To mitigate this, the casualties are loaded on the aircraft head first with their head elevated at least 30 degrees. Landing can be rough and may produce bouncing of the litter up to 6 inches or more, which could affect ICP and blood pressure. Figures 5 and 6 show the accelerometer data that depict movement of the plane (top graph) and associated ICP (bottom graph) during two aeromedical flights. As illustrated by these two graphs, ICP varies considerably on one while the other is less affected by the flight.

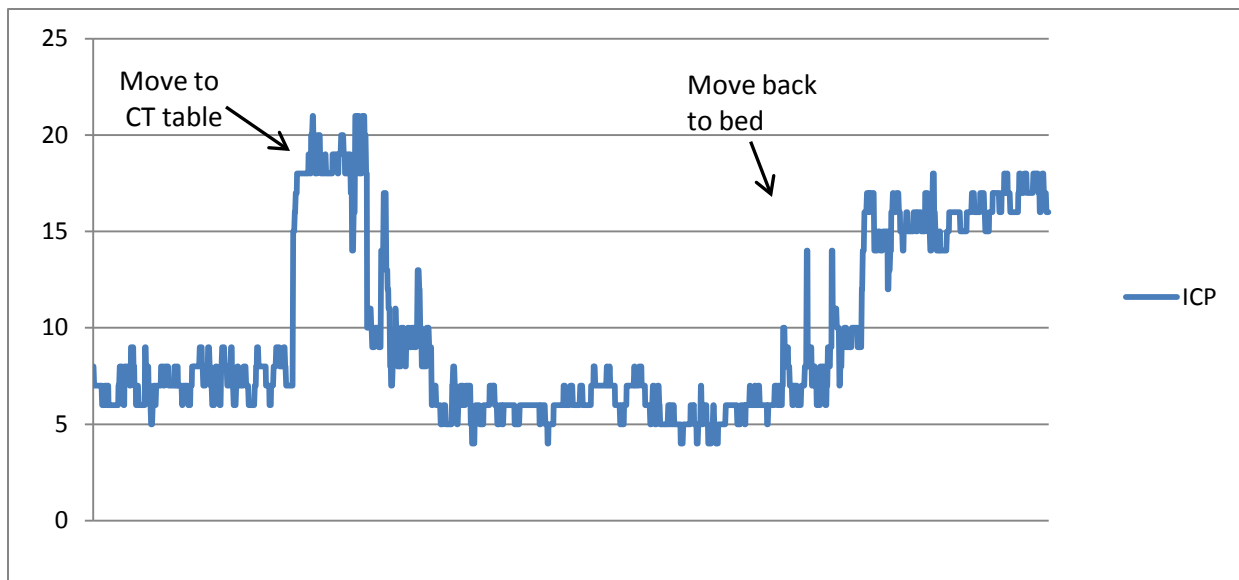


Figure 2. In-Hospital Movement ICP Measurement, Patient 1

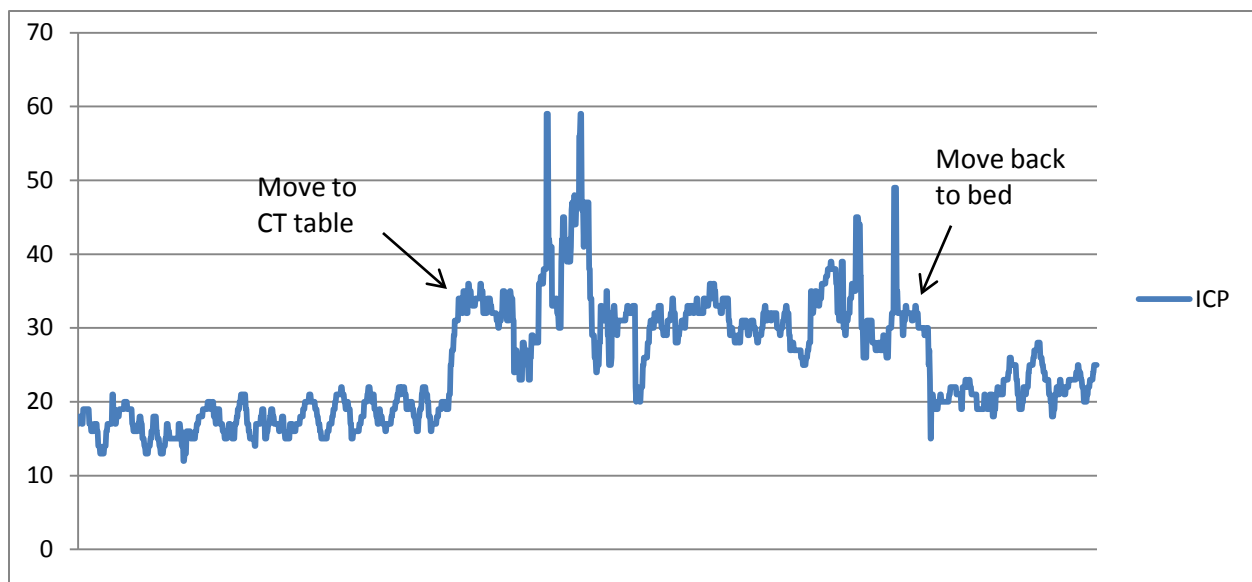


Figure 3. In-Hospital Movement ICP Measurement, Patient 2

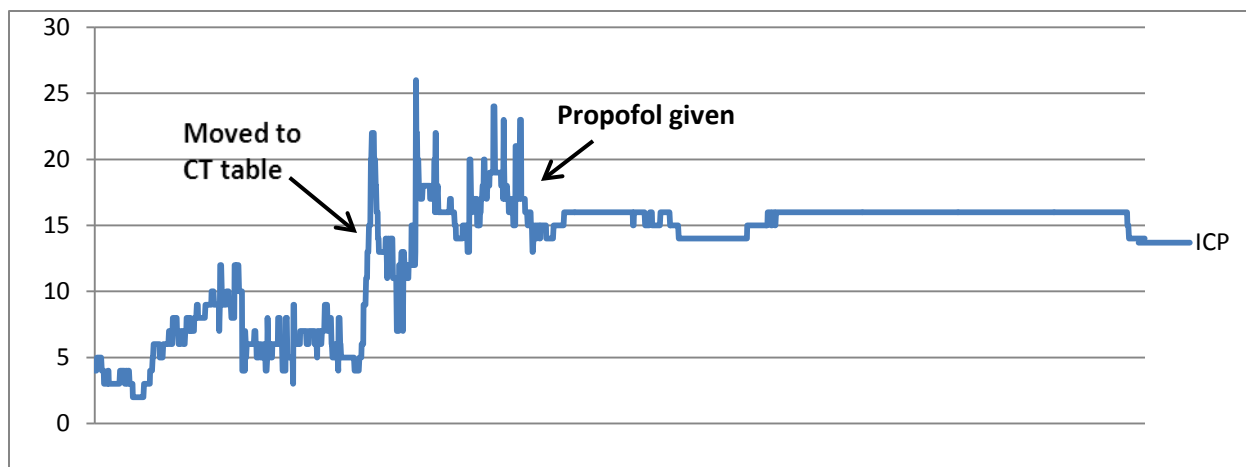


Figure 4. In-Hospital Movement ICP Measurement, Patient 3

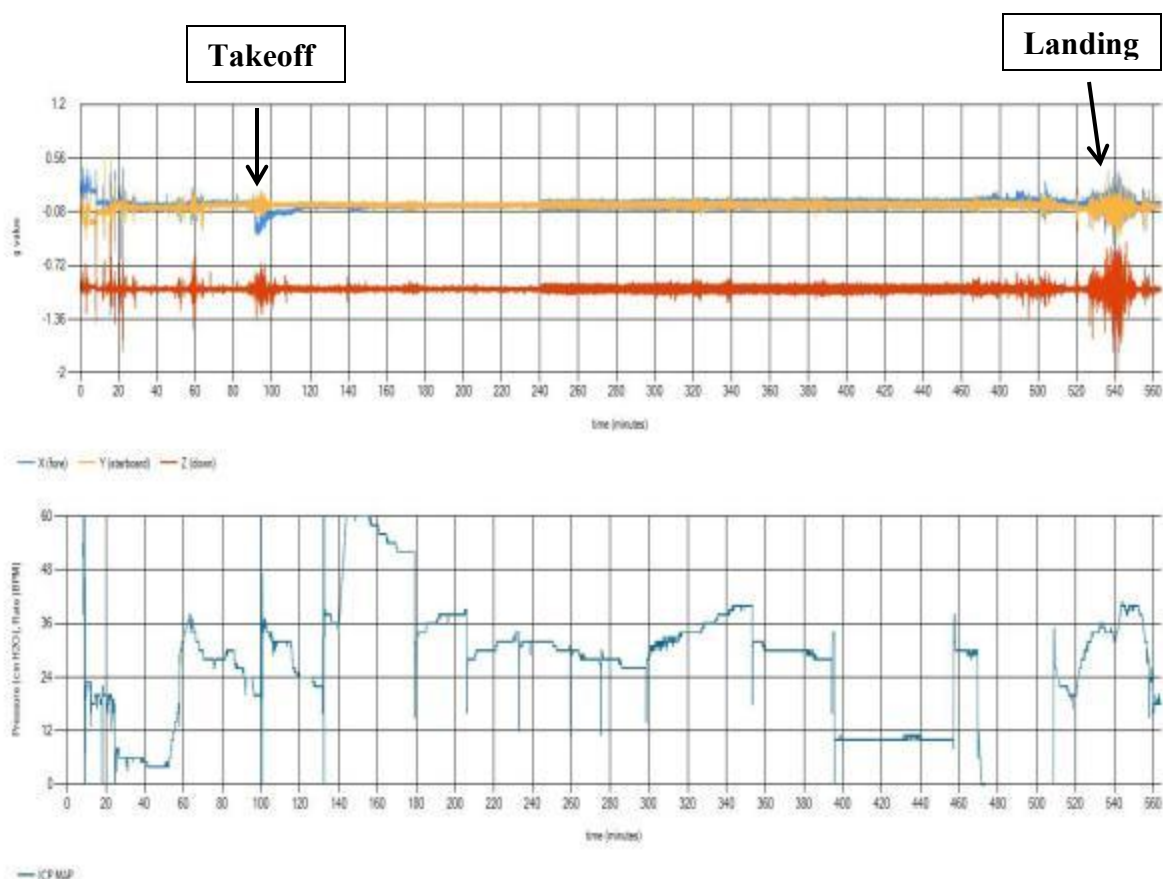


Figure 5. In-Theater Movement ICP Measurement, Patient 1

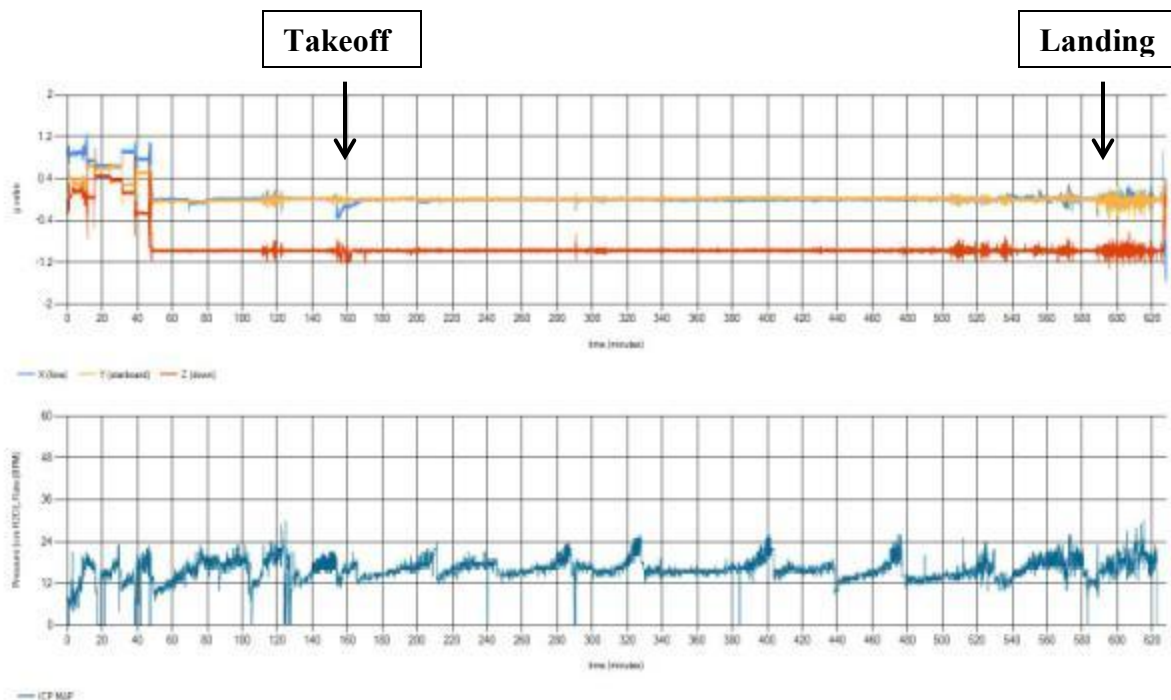


Figure 6. In-Theater Movement ICP Measurement, Patient 2

7.0 CONCLUSIONS

Transport of patients suffering from TBI either by aeromedical transport or by ground can produce adverse effects to ICP. Although extremely invasive, hemicraniectomy and sedation before aeromedical transport appeared to produce less drastic increases in ICP than those patients who had their skull left intact (in-hospital transports). It is unclear what effect the smaller fluctuations in ICP ($\pm 50\%$ of baseline, but < 20 mmHg) had on the outcome of the aeromedical transport patients. Because the study was observational in nature, the medical records of the patients transported were unavailable to the study team. To determine outcome differences, larger studies that include in-flight records as well as outcome data must be done.

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LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|--------------|----------------------------------|
| CCATT | Critical Care Air Transport Team |
| CPP | cerebral perfusion pressure |
| CT | computed tomography |
| ICP | intracranial pressure |
| ICU | intensive care unit |
| IQR | interquartile range |
| MAP | mean arterial pressure |
| TBI | traumatic brain injury |